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DECAY OF U235 FISSION PRODUCTS

25 July 1963

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Decay of U235 Fission Products

By

J. F. Perkins

Plasma Physics Branch
Physical Science Laboratory
Directorate of Research and Development
U. S. Army Missile Command
Redstone Arsenal, Alabama

ABSTRACT

Decay properties of mixed fission products from thermal fission of U235 have been calculated by a method employed earlier but with revised input data describing decay of individual nuclides. Input data and calculated decay rates and rates of beta and gamma energy release are presented.

DECAY OF U235 FISSION PRODUCTS

The decay properties of mixed fission products resulting from thermal fission of U235 have been calculated by a method employed previously[1], with use of revised input data describing the decay properties of individual nuclides. Total rates of release of beta and gamma energy and the gamma energy release in each of several energy groups were calculated for a range of decay times from 10^2 - 10^8 seconds by summing the contributions from individual nuclides.

Input data employed in the present calculations are listed in Table 1. The data of Table I incorporate results of experimental measurements[2] reported in the period 1957-1960, subsequent to completion of the original calculations[1] and correction of numerical errors in the original tabulation of data. Assignment of decay data to some of the shorter-lived activities remains uncertain in the absence of experimental determination of decay schemes, and is based on mass differences and shell-model systematics. The decay constant of a nuclide and its precursor are labelled λ_2 and λ_1, respectively. Fission yields, in percent, are labelled Y_1 and Y_2. Y_1 is independent yield, while Y_2 is total yield, including direct yield and the contribution from decay of preceding members of the decay chain. The energies of betas and gammas, in Mev per decay, are listed in the remaining columns of Table 1. E_B is average beta energy; E_{GT} is total gamma energy. Columns headed E_{GI} to $_{GVII}$ give gamma energy in each of seven energy groups, as follows:

Group	Gamma energy range (Mev)
I	0. 1 - 0. 4
II	0. 4 - 0. 9
III	0. 9 - 1. 35
IV	1. 35 - 1. 8
V	1. 8 - 2. 2
VI	2. 2 - 2. 6
VII	> 2. 6

The decay rate, D_i, of the i^{th} nuclide at time t after shutdown from an operating period of T seconds at constant power corresponding to F fissions per second is

$$D_i(t) = 0.01\ F\left[A_i \exp(-\lambda_{1i}t) + B_i \exp(-\lambda_{2i}t)\right]$$

Where

$$A_i = \frac{-(Y_{2i} - Y_{1i})}{(\lambda_{1i} - \lambda_{2i})} \cdot \lambda_{2i} \cdot \left[1 - \exp(-\lambda_{1i}T)\right]$$

$$B_i = \left[\frac{(Y_{2i} - Y_{1i})}{(\lambda_{1i} - \lambda_{2i})} \lambda_{1i} + Y_{1i}\right] \left[1 - \exp(-\lambda_{2i}T)\right].$$

Total rates of energy release are obtained by summing over all nuclides:

$$D(t) = \sum_i D_i(t)$$

$$B(t) = \sum_i D_i(t) \cdot E_{B,i}$$

$$\Gamma_T(t) = \sum_i D_i(t) \cdot E_{GT,i}$$

$$\Gamma_I(t) = \sum_i D_i(t) \cdot E_{GI,i}$$

. . . .

$$\Gamma_7(t) = \sum_i D_i(t) \cdot E_{GVII,i}$$

Results of calculations are shown in Figures 1-5 for instantaneous fission and operating periods of 1, 10, 100, and 1000 hours, and for decay times of 10^2 - 10^8 seconds.* Energy release rates in some of the gamma energy groups differ appreciably from the previous results[1] for certain ranges of decay times. Total rates of beta and gamma energy release for $t > 10^3$ seconds differ only slightly from those obtained earlier and are in reasonable agreement with experiment. The total rate of gamma energy release for 10^2 sec $\leq t \leq 10^3$ sec is somewhat higher than previously calculated and is in good agreement with measured values.[3]

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* These results and the data of Table I have been circulated in tabular form but have not been presented previously in report form.

Table I. NUCLEAR DATA USED AS INPUT FOR CALCULATIONS OF FISSION PRODUCT DECAY

NUCLIDE	LAMBDA 1	LAMBDA 2	Y1	Y2	EB	EG T	EG I	EG II	EG III	EG IV	EG V	EG VI	EG VII
SE81	-2 116	-3 641	.004	.140	.458	.150	.150	.000	.000	.000	.000	.000	.000
SE83M	1 100	-1 103	.000	.300	1.397	.150	.150	.000	.000	.000	.000	.000	.000
SE83	1 100	-3 462	.000	.240	.577	1.126	.176	.000	.750	.000	.000	.000	.000
SE84	1 100	-2 578	.000	1.000	.715	.300	.300	.000	.000	.000	.000	.000	.000
BR83	-3 462	-4 836	.300	.540	.342	.004	.000	.000	.000	.000	.000	.000	.000
BR84	-2 578	-3 350	.000	1.000	1.227	1.849	.006	.461	.120	.066	.346	.183	.647
BR85	1 100	-2 385	.000	1.300	1.036	.000	.000	.000	.000	.000	.000	.000	.000
BR87	1 100	-1 123	.000	2.500	1.800	2.430	.000	.000	.000	.000	.000	.000	2.430
KR83M	-4 836	-3 101	.000	.540	.039	.002	.000	.000	.000	.000	.000	.000	.000
KR85M	-2 385	-4 438	.000	1.300	.252	.157	.157	.000	.000	.000	.000	.000	.000
KR85	-4 438	-8 207	.000	.260	.221	.004	.000	.004	.000	.000	.000	.000	.000
KR87	1 100	-3 148	.000	2.500	1.341	1.365	.000	.507	.000	.000	.102	.977	.000
KR88	1 100	-4 688	.900	3.600	.372	1.915	.105	.144	.036	.217	.594	.816	.000
KR89	153	-2 361	1.900	4.400	1.405	2.330	.000	.000	.000	1.105	.000	.000	1.225
RB88	-4 688	-3 641	.000	3.600	2.047	.759	.000	.000	.145	.021	.465	.000	.128
RB89	-2 361	-3 770	.400	4.800	.568	2.436	.000	.109	1.473	.056	.000	.643	.154
RB90	-1 210	-2 428	1.000	5.800	.750	4.944	.000	.084	.130	.190	.180	.150	4.210
RB91	-1 693	-3 825	.800	2.000	1.270	3.000	.000	.000	.000	.000	.000	.000	3.000
RB92	230	-2 866	2.500	5.300	3.435	.000	.000	.000	.000	.000	.000	.000	.000
SR89	-3 770	-6 157	.000	4.800	.556	.000	.000	.000	.000	.000	.000	.000	.000
SR90	-2 428	-9 784	.000	5.800	.169	.000	.000	.000	.000	.000	.000	.000	.000
SR91	-3 625	-4 198	3.000	5.800	.624	.840	.000	.307	.335	.198	.000	.000	.000
SR92	-2 866	-4 713	.700	6.000	.214	1.285	.000	.044	.000	1.242	.000	.000	.000
SR93	1 100	-2 165	1.600	6.300	1.269	1.093	.000	.400	.436	.257	.000	.000	.000
SR94	1 100	-2 578	2.400	5.900	1.055	.930	.030	.000	.900	.000	.000	.000	.000

Table I. NUCLEAR DATA USED AS INPUT FOR CALCULATIONS OF FISSION PRODUCT DECAY - Continued

NUCLIDE	LAMBDA 1	LAMBDA 2	Y1	Y2	EB	EG T	EG I	EG II	EG III	EG IV	EG V	EG VI	EG VII
Y90	-9 784	-5 301	.000	5.800	.912	.000	.000	.000	.000	.000	.000	.000	.000
Y91M	-4 198	-3 231	.000	3.400	.028	.523	.000	.523	.000	.000	.000	.000	.000
Y91	-4 198	-6 131	.000	5.800	.593	.004	.000	.000	.004	.000	.000	.000	.000
Y92	-4 713	-4 535	.000	6.000	1.386	.485	.025	.065	.201	.170	.018	.005	.000
Y93	-2 165	-4 193	.100	6.400	1.151	.350	.000	.350	.000	.000	.000	.000	.000
Y94	-2 578	-3 700	.500	6.400	1.962	.978	.000	.000	.558	.420	.000	.000	.000
Y95	1 100	-2 110	1.000	6.300	1.603	.900	.000	.000	.900	.000	.000	.000	.000
ZR95	-2 110	-6 123	.000	6.300	.111	.739	.000	.739	.000	.000	.000	.000	.000
ZR97	1 100	-4 113	1.600	5.900	.748	.042	.000	.000	.033	.009	.000	.000	.000
NB95M	-6 123	-5 214	.000	.060	.000	.235	.235	.000	.000	.000	.000	.000	.000
NB95	-6 123	-6 229	.000	6.300	.045	.760	.000	.760	.000	.000	.000	.000	.000
NB97M	-4 113	-1 116	.000	5.800	.000	.747	.000	.747	.000	.000	.000	.000	.000
NB97	-4 113	-3 156	.200	6.100	.467	.669	.000	.658	.010	.000	.000	.000	.000
MO99	-2 302	-5 283	.000	6.100	.405	.126	.022	.104	.000	.000	.000	.000	.000
MO101	1 100	-3 770	.000	5.000	.418	1.663	.073	.440	.455	.360	.333	.000	.000
MO102	1 100	-2 100	.000	4.100	.436	.000	.000	.000	.000	.000	.000	.000	.000
MO105	1 100	-2 578	.000	.600	1.740	1.500	.000	.000	.000	1.500	.000	.000	.000
TC99M	-5 283	-4 321	.000	5.300	.000	.140	.140	.000	.000	.000	.000	.000	.000
TC101	-3 770	-3 808	.000	5.000	.467	.357	.285	.055	.004	.000	.000	.000	.000
TC102A	-2 100	139	.000	2.050	1.660	.364	.000	.341	.022	.000	.000	.000	.000
TC102B	-2 100	-2 257	.000	2.050	.794	2.000	.000	.000	2.000	.000	.000	.000	.000
TC105	-2 578	-2 116	.300	.900	.885	1.300	.000	.000	1.300	.000	.000	.000	.000
RU103	-2 960	-6 201	.000	3.000	.065	.498	.003	.493	.000	.000	.000	.000	.000
RU105	-2 116	-4 423	.000	.900	.414	.726	.000	.726	.000	.000	.000	.000	.000
RU106	1 100	-7 220	.000	.380	.010	.000	.000	.000	.000	.000	.000	.000	.000

Table I. NUCLEAR DATA USED AS INPUT FOR CALCULATIONS OF FISSION PRODUCT DECAY - Continued

NUCLIDE	LAMBDA 1	LAMBDA 2	Y1	Y2	EB	EG T	EG I	EG II	EG III	EG IV	EG V	EG VI	EG VII
RU107	-2 770	-2 241	.040	.200	.960	.220	.220	.000	.000	.000	.000	.000	.000
RH103M	-6 201	-3 203	.000	3.000	.039	.001	.000	.000	.000	.000	.000	.000	.000
RH105M	-4 426	-1 154	.000	.900	.000	.130	.130	.000	.000	.000	.000	.000	.000
RH105	-4 428	-5 550	.000	.900	.146	.096	.096	.000	.000	.000	.000	.000	.000
RH106	-7 220	-1 231	.000	.380	1.358	.328	.000	.264	.026	.016	.006	.007	.003
RH107	-2 241	-3 526	.000	.200	.401	.391	.363	.028	.000	.000	.000	.000	.000
SN127	1 100	-4 935	.000	.130	.430	2.000	.000	.000	.000	.000	2.000	.000	.000
SN128	1 100	-3 203	.000	.330	.470	.000	.000	.000	.000	.000	.000	.000	.000
SN130	1 100	-2 444	.000	1.400	.782	.500	.000	.500	.000	.000	.000	.000	.000
SB127	-4 935	-5 217	.000	.130	.374	.506	.054	.452	.000	.000	.000	.000	.000
SB128	-3 203	-2 116	.040	.370	1.198	1.070	.320	.750	.000	.000	.000	.000	.000
SB129	1 100	-4 458	.100	.900	.422	.897	.236	.661	.000	.000	.000	.000	.000
SB130	-3 203	-2 115	.600	2.000	1.198	2.650	.000	.850	.000	1.800	.000	.000	.000
SB131	-2 340	-3 502	1.200	2.600	.651	1.020	.000	.000	1.020	.000	.000	.000	.000
SB132	-2 526	-2 550	2.000	3.300	2.149	1.600	.000	.000	1.556	.000	.000	.044	.000
SB133	1 100	-2 262	.000	3.700	.751	2.460	.000	.000	.000	.000	.160	2.300	.000
TE127M	-5 217	-7 764	.000	.021	.093	.001	.000	.000	.000	.000	.000	.000	.000
TE127A	-5 217	-4 205	.000	.110	.224	.004	.000	.004	.000	.000	.000	.000	.000
TE127B	-7 764	-4 205	.000	.021	.224	.004	.000	.004	.000	.000	.000	.000	.000
TE129M	-4 458	-6 243	.000	.350	.106	.000	.000	.000	.000	.000	.000	.000	.000
TE129A	-4 458	-3 186	.000	.550	.457	.236	.002	.098	.116	.000	.000	.000	.000
TE129B	-6 243	-3 186	.000	.350	.457	.235	.002	.098	.116	.000	.000	.000	.000
TE131M	-3 502	-5 669	.000	.440	.145	1.442	.259	.642	.560	.000	.000	.000	.000
TE131A	-3 502	-3 462	.200	2.450	.742	.491	.157	.216	.116	.000	.000	.000	.000
TE131B	-5 669	-3 462	.000	.100	.742	.491	.157	.216	.116	.000	.000	.000	.000

Table I. NUCLEAR DATA USED AS INPUT FOR CALCULATIONS OF FISSION PRODUCT DECAY - Continued

NUCLIDE	LAMBDA 1	LAMBDA 2	Y1	Y2	EG	EG T	EG I	EG II	EG III	EG IV	EG V	EG VI	EG VII
TE132	-2 550	-5 247	1.100	4.400	.061	.231	.231	.000	.000	.000	.000	.000	.000
TE133M	-2 282	-3 183	1.800	5.500	.132	.268	.268	.000	.000	.000	.000	.000	.000
TE133	-3 183	-2 576	.600	6.100	.619	1.300	.000	.600	.700	.000	.000	.000	.000
TE134	-1 154	-3 263	3.600	7.100	.514	.000	.000	.000	.000	.000	.000	.000	.000
I131A	-3 462	-6 996	.000	2.560	.183	.392	.313	.078	.000	.000	.000	.000	.000
I131B	-5 669	-6 996	.000	.340	.183	.392	.313	.078	.000	.000	.000	.000	.000
I132	-5 247	-4 837	.000	4.400	.485	2.130	.000	1.514	.302	.104	.104	.046	.000
I133	-2 576	-5 917	.500	6.600	.493	.565	.000	.551	.000	.014	.000	.000	.000
I134	-3 263	-3 220	.900	8.000	.580	2.614	.004	1.640	.600	.370	.000	.000	.000
I135	-1 115	-4 287	1.700	6.100	.316	1.771	.000	.121	.952	.598	.102	.000	.000
I136	1 100	-2 825	.000	3.100	1.850	2.698	.098	.040	1.310	.100	.090	.440	.620
XE133M	-5 917	-5 349	.000	.160	.207	.026	.026	.000	.000	.000	.000	.000	.000
XE133	-5 917	-5 151	.000	6.600	.155	.027	.000	.000	.000	.000	.000	.000	.000
XE135M	-4 287	-3 741	.000	1.800	.104	.416	.000	.416	.000	.000	.000	.000	.000
XE135	-4 287	-4 212	.300	6.400	.304	.261	.243	.017	.000	.000	.000	.000	.000
XE137	-1 315	-2 296	1.300	5.100	.911	1.215	.000	.030	.000	1.185	.000	.000	.000
XE138	117	-3 680	2.600	4.600	.579	1.280	.000	.235	.000	.000	1.045	.000	.000
CS137	-2 296	-9 732	.000	6.100	.173	.000	.000	.000	.000	.000	.000	.000	.000
CS138	-3 680	-3 361	1.100	5.700	1.093	2.177	.008	.197	.252	1.068	.000	.398	.253
CS139	-1 169	-2 122	2.000	5.800	1.500	.750	.000	.000	.000	.750	.000	.000	.000
CS140	-1 433	-1 105	2.700	5.500	1.949	1.400	.000	.400	1.000	.000	.000	.000	.000
CS142	1 100	-1 116	.000	3.200	2.423	1.400	.000	.400	1.000	.000	.000	.000	.000
BA137M	-9 732	-2 444	.000	5.800	.066	.595	.000	.595	.000	.000	.000	.000	.000
BA139	-2 122	-3 136	.400	6.200	.776	.413	.141	.000	.000	.272	.000	.000	.000
BA140	-1 105	-6 527	.900	6.400	.310	.189	.026	.150	.000	.000	.000	.000	.000

Table I. NUCLEAR DATA USED AS INPUT FOR CALCULATIONS OF FISSION PRODUCT DECAY - Concluded

NUCLIDE	LAMBDA 1	LAMBDA 2	Y1	Y2	EB	EG T	EG I	EG II	EG III	EG IV	EG V	EG VI	EG VII
BA141	1 100	-3 642	1.400	5.900	1.059	.180	.180	.000	.000	.000	.000	.000	.000
BA142	-1 116	-2 105	2.200	5.400	.776	.300	.300	.000	.000	.000	.000	.000	.000
LA140	-6 627	-5 479	.000	6.400	.493	2.231	.066	.435	.099	1.530	.000	.098	.003
LA141	-3 642	-4 507	.100	6.000	.938	.027	.000	.000	.000	.027	.000	.000	.000
LA142	-2 105	-3 136	.500	5.900	1.325	1.344	.000	.460	.062	.106	.178	.341	.187
LA143	-1 231	-3 608	1.000	6.000	1.200	.075	.000	.000	.000	.075	.000	.000	.000
CE141	-4 507	-6 251	.000	6.000	.146	.097	.097	.000	.000	.000	.000	.000	.000
CE143	-3 608	-5 583	.000	6.000	.428	.332	.125	.133	.066	.000	.000	.000	.000
CE144	1 100	-7 281	.300	5.700	.093	.016	.012	.000	.000	.000	.000	.000	.000
CE145	1 100	-2 385	.000	4.000	.512	.900	.000	.000	.900	.000	.000	.000	.000
CE146	1 100	-3 825	.000	3.100	.225	.372	.370	.000	.000	.000	.000	.000	.000
PR143	-5 583	-6 573	.000	6.000	.315	.000	.000	.000	.000	.000	.000	.000	.000
PR144	-7 281	-3 660	.000	5.700	1.214	.032	.000	.011	[illegible]	.004	.017	.000	.000
PR145	-2 385	-4 321	.000	4.000	.640	.047	.000	.000	.000	.000	.000	.000	.000
PR146	-3 825	-3 481	.000	3.100	1.254	1.112	.000	.620	.000	.492	.000	.000	.000
ND147	1 100	-6 692	.000	2.400	.271	.137	.014	.095	.000	.000	.000	.000	.000
ND149	1 100	-4 963	.000	1.100	.455	.330	.200	.130	.000	.000	.000	.000	.000
ND151	1 100	-3 770	.000	.440	.725	1.241	.100	.115	1.026	.000	.000	.000	.000
PM147	-6 692	-8 872	.000	2.400	.062	.000	.000	.000	.000	.000	.000	.000	.000
PM149	-4 963	-5 357	.000	1.100	.362	.285	.285	.000	.000	.000	.000	.000	.000
PM151	-3 770	-5 683	.010	.450	.382	.455	.263	.175	.000	.015	.000	.000	.000
SM151	-5 688	-9 301	.000	.450	.020	.020	.000	.000	.000	.000	.000	.000	.000
SM153	1 100	-5 410	.000	.150	.314	.043	.036	.000	.000	.000	.000	.000	.000

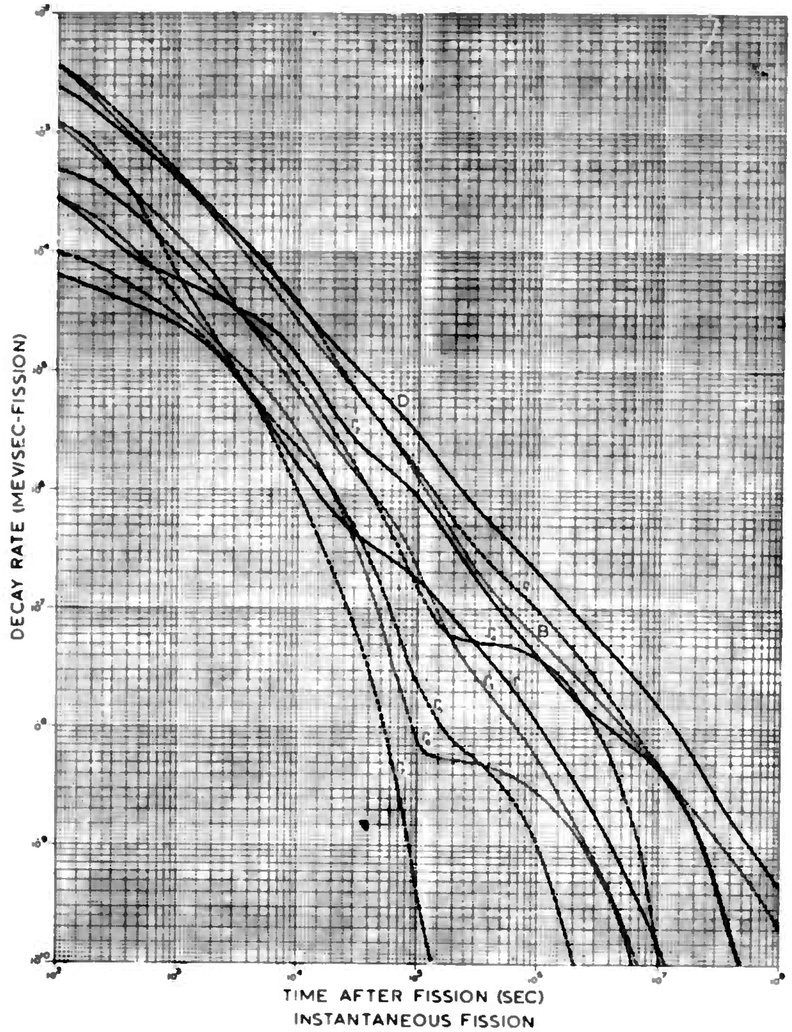

Figure 1. DECAY RATES DUE TO INSTANTANEOUS FISSION

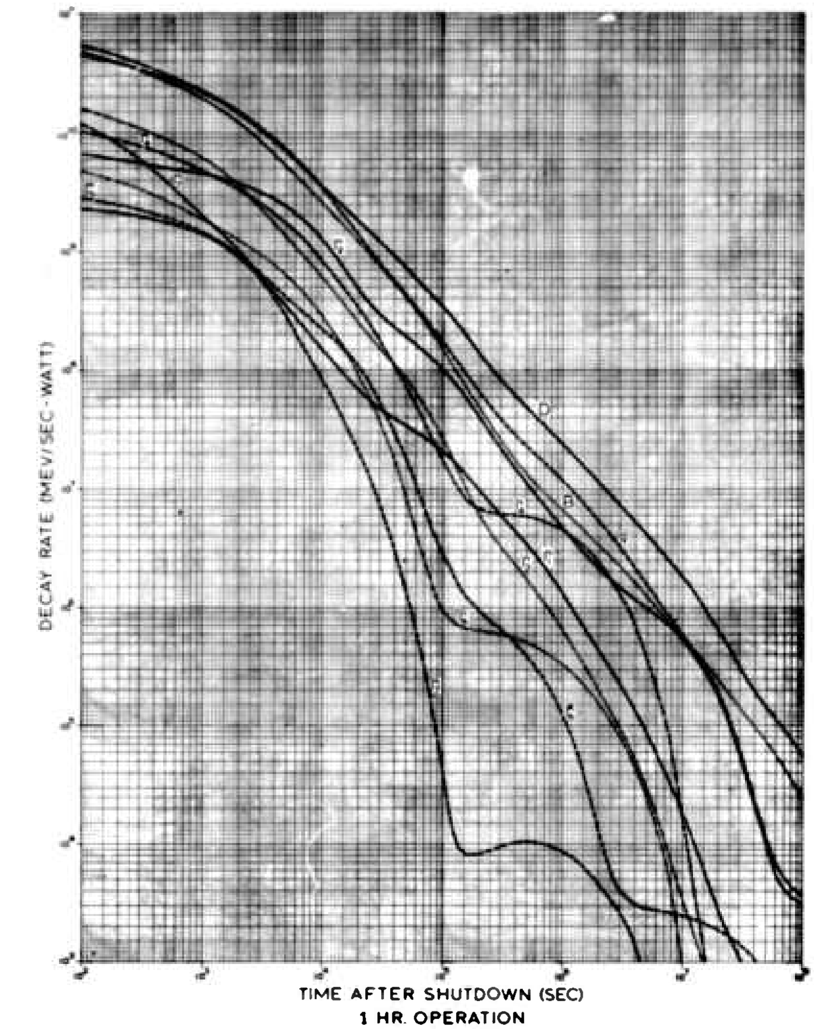

Figure 2. DECAY RATES DUE TO 1-HOUR REACTOR OPERATION

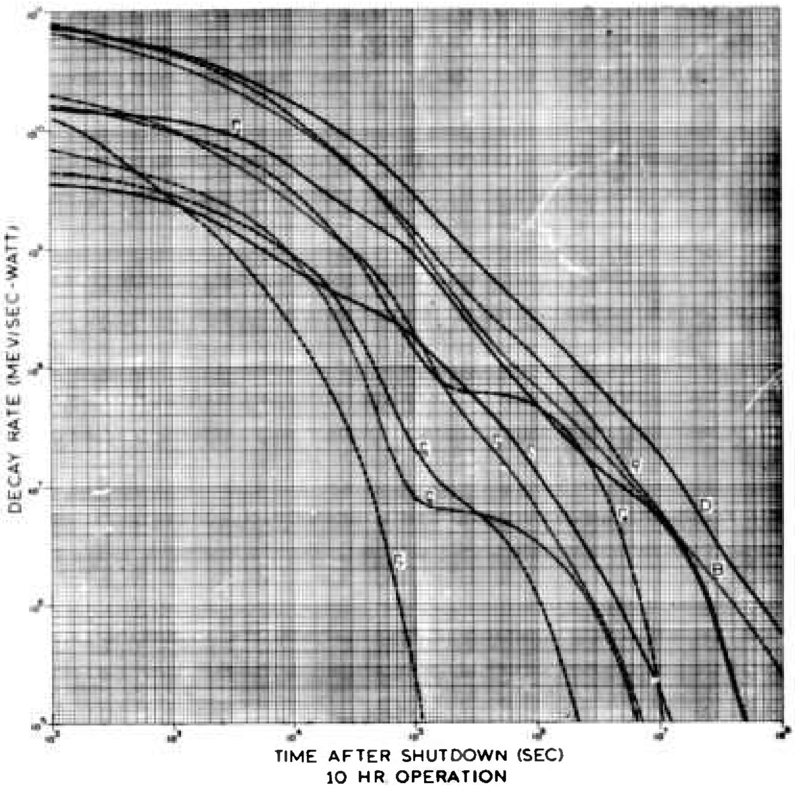

Figure 3. DECAY RATES DUE TO 10-HOUR REACTOR OPERATION

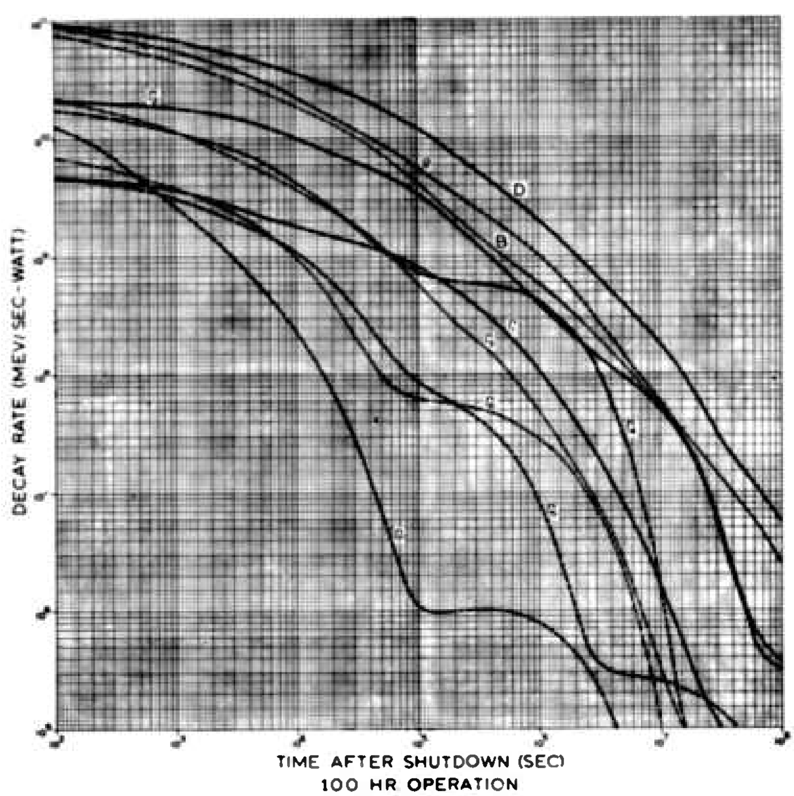

Figure 4. DECAY RATES DUE TO 100-HOUR REACTOR OPERATION

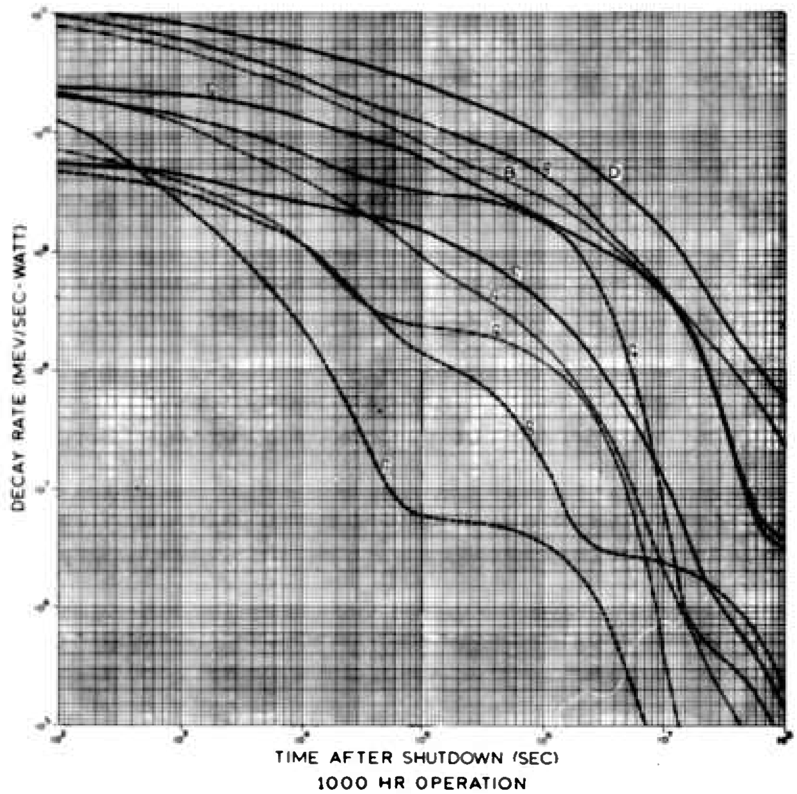

Figure 5. DECAY RATES DUE TO 1000-HOUR REACTOR OPERATION

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APPROVED:

John P. Hallowes Jr.

JOHN P. HALLOWES, JR
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1. Fission product activity
2. Fission products--Decay
3. Nuclei--Decay
4. Nuclei--Energy
5. Uranium isotopes (Radio-active)--Decay
6. Uranium isotopes (Radio-active)--Fission
7. U235

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